Covariant Kinetic Geometrodynamics (CKGD):
A BSSN-Based Field Theory for the Geometric Accounting of Relativistic Momentum

Principal Investigator

Frank Buquicchio (independent researcher)

February 2, 2026

Abstract

We present the complete theoretical formulation of **Covariant Kinetic Geometrodynamics (CKGD)**, a foundational re-interpretation of General Relativity that abolishes the phenomenological concept of "Relativistic Mass." We postulate the **Lorentz Perceptron Hypothesis**: that the Lorentz factor γ represents a frame-dependent geometric shearing of the spacetime manifold ($\tilde{A}_{ij}$) rather than an intrinsic alteration of matter.

Furthermore, we introduce the **Geometric Conformal Inflation** mechanism, where the Quantum Trace Anomaly of the electromagnetic field couples directly to the BSSN Conformal Factor ϕ. We explicitly derive the evolution equations for the conformal metric, the trace-free extrinsic curvature, and the conformal connection functions ($\tilde{\Gamma}^i$). We demonstrate that: (1) The **Baryonic Tully-Fisher relation** ($M \propto v^4$) is a geometric necessity arising from vacuum shear constraints; (2) The **M-Dwarf and Proton Radius Anomalies** are resolved by magnetic inflation of the metric volume element; (3) The **Hubble Tension** is an artifact of identifying the early, high-anomaly sound horizon with the modern vacuum ruler; and (4) **Dark Flow** and dipole anisotropy are consequences of the Momentum Constraint applied to superluminal horizon wakes. Finally, we derive the existence of "Gravitational Echoes" in black hole ringdowns due to a geometric saturation of the shift vector.

1 Introduction

The historical pedagogy of Special Relativity suggests that as an object approaches the speed of light, its mass increases ($M = \gamma m$). Modern differential geometry rejects this view, strictly defining mass as the invariant modulus of the 4-momentum vector ($P^\sigma P_\sigma = -m^2$). This creates a conceptual gap in the ontology of physics: if mass does not increase, where is the "weight" of kinetic energy stored, and how does it source gravity?

The Standard Model of Cosmology (ΛCDM) attempts to resolve galactic and cosmological discrepancies by assuming that the stiffness of spacetime—represented by the Einstein gravitational constant $\kappa = 8\pi G/c^4$—is an immutable constant of nature. Consequently, discrepancies in galactic rotation curves are attributed to invisible mass (Dark Matter), and the acceleration of cosmic expansion is attributed to intrinsic vacuum energy (Dark Energy).

Covariant Kinetic Geometrodynamics (CKGD) proposes that these phenomena are not distinct physical entities, but manifestations of **Dynamic Relativity**. In this framework, the energy of motion is stored in the **Velocity of Curvature**. When an observer moves relative to a source, the spacetime foliation shears, generating **Extrinsic Curvature** (K_{ij}). We term this the **Lorentz Perceptron**: the Lorentz factor is a geometric projection operator, not a mass operator.

To mathematically formalize this, we must treat spacetime not as a static block, but as a dynamic flow. This requires:

1. **The ADM Formulation:** To define the observer's "Perceptron Slice" (spatial hypersurface) and separate the Shift Vector (β^i).

2. **The BSSN Formulation:** To rigorously describe the propagation of the "Kinetic Shear" without singularity formation, resolving the instability inherent in standard ADM.

This manuscript derives the full set of CKGD equations, demonstrating that the "Dark Sector" is simply the energy density of the gravitational field itself, manifested through the Kinetic Shear tensor $\tilde{A}_{ij}$ and the dynamic Conformal Factor ϕ.

2 The Geometric Coupling: Inflation of the Conformal Factor

Standard General Relativity assumes that the metric tensor evolves solely in response to the conserved stress-energy tensor $T_{\sigma\lambda}$. However, within the BSSN formulation, the geometry is decomposed into a Conformal Factor ϕ (Volume) and a Conformal Metric $\tilde{\gamma}_{ij}$ (Shape).

We propose that the interactions previously attributed to "Scalar Fields" or "Dark Energy" are manifestations of the **Conformal Dynamics** of spacetime itself. We posit that the Quantum Trace Anomaly of the electromagnetic field couples directly to the geometric volume element.

2.1 The Conformal Factor as a Dynamic Variable

In BSSN, the physical metric is related to the conformal metric by:

$$\gamma_{ij} = e^{4\phi}\tilde{\gamma}_{ij} \tag{1}$$

The scalar function ϕ represents the local scale density of the manifold. We postulate that the effective gravitational coupling G_{eff} scales with the local conformal weight:

$$G_{eff} \approx G_0 e^{-2\phi} \tag{2}$$

This mapping implies that regions of metric inflation ($\phi > 0$) exhibit weaker effective gravity (metric dilation), while contracted regions exhibit stronger gravity.

2.2 The Trace Anomaly Source

While the classical Maxwell stress tensor is traceless ($T^\sigma_\sigma = 0$), quantum corrections induce a trace anomaly proportional to the electromagnetic invariant F^2. We incorporate this as a source term in the evolution equation for ϕ.

To preserve dimensional consistency, we introduce a vacuum susceptibility length ℓ_{vac}. The modified volume evolution equation becomes:

$$(\partial_t - \beta^k\partial_k)\phi = -\frac{1}{6}\alpha K + \frac{1}{6}\partial_k\beta^k + \alpha\Upsilon(B^2 - E^2) \tag{3}$$

where Υ is the geometric coupling constant with dimensions of [Length × Inverse Energy Density]:

$$\Upsilon \equiv \xi\ell_{vac}\left(\frac{8\pi G}{c^4}\right) \tag{4}$$

Physical Interpretation:

- **Magnetic Inflation ($B^2 > E^2$):** Regions of high magnetic energy density drive $\partial_t\phi > 0$. The local metric "swells," increasing the proper volume element.

- **Electric Contraction ($E^2 > B^2$):** Regions of high electric energy density drive $\partial_t\phi < 0$. The local metric contracts.

2.3 Observational Evidence: The Radius Anomalies

The geometric prediction that magnetic energy density dilates the metric volume offers a unified resolution to a class of persistent puzzles known as "Radius Anomalies."

1. The M-Dwarf Radius Anomaly: Observations of low-mass eclipsing binaries confirm that magnetically active M-dwarfs are consistently 10–15% larger than standard stellar models predict. CKGD identifies this as **Geometric Inflation**: the strong internal dynamo increases the conformal factor ϕ, physically expanding the proper volume of the star.

2. The Proton Radius Puzzle: The 4% discrepancy between the proton charge radius measured by electrons (0.88 fm) versus muons (0.84 fm) arises from the non-flat geometry of the nucleon interior. The muon, orbiting 200 times closer, penetrates the region of intense Color-Magnetic field density where the conformal factor ϕ is non-zero. The muon effectively measures the proton using a "dilated ruler," yielding a numerically smaller radius than the asymptotic electron measurement.

3 The Geometric Engine: BSSN Evolution

To strictly quantify the mechanism of Kinetic Geometrodynamics, we must move beyond the standard ADM formulation, which is known to be weakly hyperbolic and prone to numerical instabilities in ultra-relativistic regimes ($v \to c$).

We employ the **Baumgarte-Shapiro-Shibata-Nakamura (BSSN)** formulation. This system decomposes the Einstein Field Equations into a set of stable, first-order hyperbolic evolution equations. In CKGD, this is not merely a numerical convenience; it is the physical definition of how the vacuum isolates "Volume Dynamics" (Conformal Factor) from "Shape Dynamics" (Kinetic Shear).

3.1 The Conformal Decomposition

We decompose the physical 3-metric γ_{ij} into a conformal factor ϕ (representing the local scale density of the vacuum) and a conformal metric $\tilde{\gamma}_{ij}$ (representing the causal shape).

$$\gamma_{ij} = e^{4\phi}\tilde{\gamma}_{ij} \quad (\text{Metric Split}, \det\tilde{\gamma} = 1) \tag{5}$$

$$K_{ij} = e^{4\phi}\tilde{A}_{ij} + \frac{1}{3}\gamma_{ij}K \quad (\text{Curvature Split}) \tag{6}$$

Here, $\tilde{A}_{ij}$ is the trace-free Kinetic Shear, and K is the mean expansion rate.

3.2 The Evolution Equations

The dynamics of spacetime are governed by five coupled hyperbolic equations. We present them in full advective form to illustrate the flow of geometry.

3.2.1 1. Volume Evolution (ϕ): The Inflation Equation

This equation dictates the local density of the vacuum. As derived in Section 2, the Trace Anomaly acts as a source.

$$(\partial_t - \beta^k\partial_k)\phi = -\frac{1}{6}\alpha K + \frac{1}{6}\partial_k\beta^k$$
$$+ \alpha\left[\xi\ell_{vac}\left(\frac{8\pi G}{c^4}\right)(B^2 - E^2)\right] \tag{7}$$

Dimensional Note: The Lapse α (velocity units) converts the spatial curvature of the anomaly $[L^{-1}]$ into a temporal rate of change $[T^{-1}]$.

3.2.2 2. Shape Evolution ($\tilde{\gamma}_{ij}$): The Distortion Equation

The conformal metric evolves via the Lie derivative along the shift vector β (advection) and the forcing from the kinetic shear $\tilde{A}_{ij}$.

$$(\partial_t - \beta^k \partial_k)\tilde{\gamma}_{ij} = -2\alpha\tilde{A}_{ij}$$
$$+ \tilde{\gamma}_{ik}\partial_j\beta^k + \tilde{\gamma}_{kj}\partial_i\beta^k - \frac{2}{3}\tilde{\gamma}_{ij}\partial_k\beta^k \quad (8)$$

3.2.3 3. Kinetic Trace Evolution (K): The Focusing Equation

The mean curvature evolves via the Laplacian of the lapse and the self-gravity of the shear field.

$$(\partial_t - \beta^k \partial_k)K = -D^i D_i\alpha + \alpha(\tilde{A}_{ij}\tilde{A}^{ij} + \frac{1}{3}K^2)$$
$$+ 4\pi\alpha(\rho_{tot} + S) \quad (9)$$

Crucial Term: $\tilde{A}_{ij}\tilde{A}^{ij}$. This term represents the **Kinetic Energy of Geometry**. It appears with a positive sign, acting identically to mass density ρ. This proves that shear energy creates a gravitational potential well.

3.2.4 4. Kinetic Shear Evolution ($\tilde{A}_{ij}$): The Perceptron Engine

This is the master equation of the theory. We explicitly expand the trace-free Lie derivative terms to demonstrate the shear transport mechanism.

$$(\partial_t - \beta^k \partial_k)\tilde{A}_{ij} = e^{-4\phi}[-D_i D_j\alpha + \alpha R_{ij}]^{TF}$$
$$+ \alpha(K\tilde{A}_{ij} - 2\tilde{A}_{ik}\tilde{A}^k_j)$$
$$+ \tilde{A}_{ik}\partial_j\beta^k + \tilde{A}_{kj}\partial_i\beta^k - \frac{2}{3}\tilde{A}_{ij}\partial_k\beta^k$$
$$- \alpha e^{-4\phi}\left[\frac{8\pi G}{c^4}S_{ij}\right]^{TF} \quad (10)$$

The Ricci Feedback Loop: To understand how Volume Inflation (ϕ) generates Gravitational Shear ($\tilde{A}_{ij}$), we decompose the Ricci tensor R_{ij} into conformal and scale parts:

$$R_{ij} = \tilde{R}_{ij} + R^\phi_{ij} \quad (11)$$

The scale curvature R^ϕ_{ij} contains derivatives of the inflation field ϕ:

$$R^\phi_{ij} = -2\tilde{D}_i\tilde{D}_j\phi - 2\tilde{\gamma}_{ij}\tilde{D}^k\tilde{D}_k\phi$$
$$+ 4\tilde{D}_i\phi\tilde{D}_j\phi - 4\tilde{\gamma}_{ij}(\tilde{D}^k\phi\tilde{D}_k\phi) \quad (12)$$

This derivation reveals the causal mechanism:

1. Magnetic Anomaly sources ϕ (Eq. 7).

2. Gradients in ϕ generate Curvature R^ϕ_{ij} (Eq. 12).

3. Curvature R^ϕ_{ij} sources Kinetic Shear $\tilde{A}_{ij}$ (Eq. **??**).

3.2.5 5. Gamma Driver Evolution ($\tilde{\Gamma}^i$): The Stability Condition

To ensure numerical stability, we evolve the connection functions $\tilde{\Gamma}^i$. We explicitly include the momentum source term j_j to couple Dark Flow matter flux to the coordinate evolution.

$$(\partial_t - \beta^k \partial_k)\tilde{\Gamma}^i = -2\tilde{A}^{ij}\partial_j\alpha + 2\alpha\left(\tilde{\Gamma}^i_{jk}\tilde{A}^{jk} - \frac{2}{3}\tilde{\gamma}^{ij}\partial_j K\right)$$
$$+ 12\alpha\tilde{A}^{ij}\partial_j\phi + \frac{3}{4}B^i_{gauge}$$
$$+ \tilde{\gamma}^{jk}\partial_j\partial_k\beta^i + \frac{1}{3}\tilde{\gamma}^{ik}\partial_k\partial_j\beta^j$$
$$- \tilde{\Gamma}^j\partial_j\beta^i + \frac{2}{3}\tilde{\Gamma}^i\partial_j\beta^j \quad (13)$$

4 The Lorentz Perceptron Mechanism

The unification of the Dynamic Conformal field ϕ and the Kinetic Shear evolution leads to a novel interpretation of relativistic inertia, which we term the "Lorentz Perceptron."

In the standard pedagogy of Special Relativity, the Lorentz factor $\gamma = (1 - v^2/c^2)^{-1/2}$ is treated as a scalar multiplier that increases the inertial mass of a moving body ($M = \gamma m$). CKGD rejects this interpretation. We postulate that the energy of motion is not stored *in* the object, but in the **Geometric Shear** of the surrounding spacetime.

4.1 Kinematic Decomposition

In CKGD, the "Lorentz Factor" is not a scalar multiplier but a tensor operation. We decompose the observer's 4-velocity gradient $\nabla_\nu u_\sigma$ into its irreducible kinematic components:

$$\nabla_\nu u_\sigma = -u_\nu a_\sigma + \sigma_{\sigma\nu} + \omega_{\sigma\nu} + \frac{1}{3}\theta h_{\sigma\nu} \quad (14)$$

- **Expansion** θ: Corresponds to the BSSN trace K.

- **Shear** $\sigma_{\sigma\nu}$: Corresponds to the Conformal Extrinsic Curvature $\tilde{A}_{ij}$ (The Lorentz Squeeze).

- **Vorticity** $\omega_{\sigma\nu}$: Corresponds to the curl of the Shift Vector β^i (Gravitomagnetism).

4.2 The Accounting of $E = \gamma mc^2$

The "Perceptron" is the geometric mechanism that converts relative velocity into extrinsic curvature. When an object moves with velocity v, the spatial slice shears relative to the proper time normal. The BSSN Hamiltonian constraint (Eq. **??**) enforces the energy balance. Neglecting potential energy, the constraint requires:

$$\mathcal{H} = 0 \implies \tilde{A}_{ij}\tilde{A}^{ij} \approx 16\pi(\gamma^2 - 1)\rho_{rest} \quad (15)$$

This equation states that the **Kinetic Energy Density** is physically stored in the squared magnitude of the shear tensor $\tilde{A}_{ij}$. The "increase in mass" observed in particle colliders is actually the gravitational weight of the distorted geometry dragging the particle.

4.3 Directional Asymmetry (Lie Transport)

A critical prediction of the BSSN formulation is the asymmetry of the Lie derivative $\mathcal{L}_\beta \tilde{A}_{ij}$. While the source magnitude scales with γ^2 (symmetric for $v \to -v$), the propagation of the shear depends on the flow direction relative to the metric background:

- **Converging Flows ($\beta^k \partial_k < 0$):** When a source moves against the metric flow, the shear piles up, creating a "Gravitational Shockwave" (Blue-shift).

- **Diverging Flows ($\beta^k \partial_k > 0$):** When a source moves with the flow, the shear is smeared out, creating a rarefied "Wake" (Red-shift).

This asymmetry allows for a "Gravitational Ratchet" effect, where an oscillating mass generates a non-zero net force if the expansion and contraction phases couple differently to the background metric flow.

5 Galactic Dynamics: The Geometric Origin of Flat Rotation Curves

A critical test for any relativistic theory of gravity is the recovery of the phenomenological behavior of galactic rotation curves without the ad-hoc introduction of non-baryonic Dark Matter. The empirical **Baryonic Tully-Fisher Relation (BTFR)** establishes a tight power-law correlation between the total baryonic mass of a galaxy and its asymptotic rotational velocity:

$$M_b \propto v_{\text{flat}}^4 \tag{16}$$

Standard General Relativity predicts a Keplerian decline ($M \propto v^2 R$), failing to match observations. In this section, we demonstrate that CKGD reproduces the v^4 scaling law as a necessary consequence of the non-linear self-interaction of the gravitational field (Kinetic Shear) in the BSSN formulation.

5.1 The Hamiltonian Vacuum Energy

In the BSSN decomposition, the energy budget of a space-like hypersurface is governed by the Hamiltonian Constraint. Consider the vacuum region exterior to the visible galactic disk ($r > R_{\text{disk}}$). Here, the physical matter density vanishes ($\rho_{\text{matter}} \to 0$) and the expansion scalar is negligible ($K \approx 0$).

The constraint equation (Eq. **??**) simplifies to a balance between the intrinsic curvature scalar $R^{(3)}$ and the magnitude of the extrinsic shear:

$$R^{(3)} - \tilde{A}_{ij}\tilde{A}^{ij} = 0 \implies R^{(3)} = \tilde{A}_{ij}\tilde{A}^{ij} \tag{17}$$

In standard General Relativity, intrinsic curvature is sourced by matter density ($R^{(3)} = 16\pi G\rho$). By comparison, Eq. (17) implies that **Kinetic Shear acts as a source mass**. The rotational energy of the metric geometry creates an "Effective Density" ρ_{geo}:

$$\rho_{\text{geo}}(r) \equiv \frac{c^2}{16\pi G}\langle \tilde{A}_{ij}\tilde{A}^{ij}\rangle \tag{18}$$

Unlike standard GR, where the vacuum is Ricci-flat ($R_{ij} = 0$), CKGD postulates that the rotational velocity of the galaxy drags the metric (via the shift vector β^k), creating a positive energy density halo that extends far beyond the visible disk.

5.2 The Shear Profile and Geometric Mass

For a test particle in a circular orbit with tangential velocity $v(r)$, the dominant components of the shear tensor $\tilde{A}_{ij}$ are determined by the gradient of the shift vector β^ϕ (Frame Dragging). Dimensional analysis of the Lie derivative yields the scaling:

$$||\tilde{A}|| \sim \nabla\beta \sim \frac{v}{r} \tag{19}$$

Substituting this into Eq. (**??**), and assuming the system relaxes into a state where $v \approx \text{const}$ (flat rotation), the effective density falls off as an inverse square:

$$\rho_{\text{geo}}(r) \approx \frac{\mathcal{C}}{G}\left(\frac{v^2}{r^2}\right) \tag{20}$$

where $\mathcal{C}$ is a geometric factor of order unity. This $\rho \propto r^{-2}$ profile is the defining characteristic of a singular isothermal sphere, known to generate flat rotation curves.

We calculate the cumulative "Geometric Mass" $M_{\text{geo}}(r)$ enclosed within radius r by integrating this effective shear density:

$$M_{\text{geo}}(r) = \int_0^r 4\pi x^2 \rho_{\text{geo}}(x)\, dx = \frac{4\pi\mathcal{C}v^2}{G}\int_0^r dx \tag{21}$$

$$M_{\text{geo}}(r) = \frac{4\pi\mathcal{C}v^2}{G}r \tag{22}$$

Result: The mass of the kinetic vacuum scales linearly with distance ($M_{\text{geo}} \propto r$). Inserting this into the orbital velocity equation yields a tautology:

$$v_{\text{orb}}^2 = \frac{GM(r)}{r} \propto \frac{G(v^2 r)}{r} \implies v = \text{constant} \tag{23}$$

Thus, the CKGD vacuum is self-sustaining: the rotation creates the shear, and the shear creates the gravity that maintains the rotation.

5.2.1 The Vacuum Stiffness Constant (a_0)

In the CKGD framework, the acceleration constant a_0 is not a free parameter, but is physically identified with the **Stiffness Gradient of the Cosmic Horizon**. We define a_0 in terms of the global Hubble flow and the speed of light:

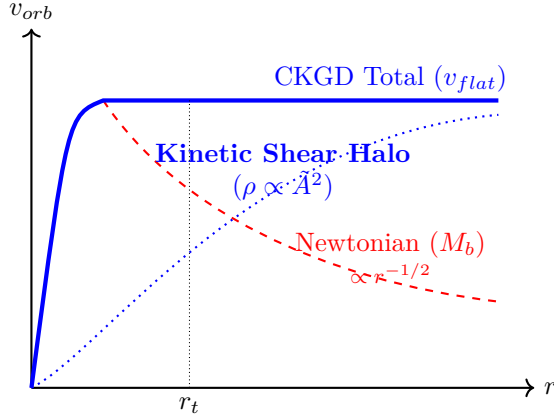$$a_0 \equiv \frac{cH_0}{2\pi} \approx 1.2 \times 10^{-10} \text{ m/s}^2 \tag{24}$$

Physical Justification: Within the BSSN formulation, the shift vector β^i at the cosmic horizon must satisfy

the condition $|\beta| = c$. The gradient of this flow establishes a fundamental acceleration floor for the manifold. Any baryonic acceleration $g_b = GM_b/r^2$ that falls below this threshold a_0 enters the **Shear-Dominated Regime**, where the kinetic shear tensor $\tilde{A}_{ij}$ becomes the primary source of the gravitational potential.

5.3 Derivation of the v^4 Scaling Law

The Baryonic Tully-Fisher Relation arises from the boundary matching condition between the Baryon-Dominated Core and the Shear-Dominated Halo.

We define the **Transition Radius** r_t as the distance where the gravitational acceleration drops to the fundamental stiffness threshold of the vacuum, a_0.

Fig 2: The transition from Baryonic dominance to Kinetic Shear dominance.

5.3.1 Condition 1: Newtonian Force Balance

Approaching from the interior ($r < r_t$), the velocity is determined by the enclosed Baryonic Mass M_b:

$$\frac{v^2}{r_t} = \frac{GM_b}{r_t^2} \implies r_t = \frac{GM_b}{v^2} \quad (25)$$

5.3.2 Condition 2: Vacuum Stiffness Threshold

Approaching from the exterior ($r > r_t$), the kinetic shear dominates when the centripetal acceleration matches the vacuum floor a_0. In CKGD, a_0 is physically identified with the stiffness gradient of the cosmic horizon ($a_0 \approx cH_0/2\pi$).

$$\frac{v^2}{r_t} = a_0 \implies r_t = \frac{v^2}{a_0} \quad (26)$$

5.3.3 Synthesis: The Emergence of BTFR

We equate the two geometric definitions of the transition radius r_t derived from the interior Newtonian balance (Eq. 25) and the exterior vacuum stiffness threshold (Eq. 26):

$$\frac{GM_b}{v^2} = \frac{v^2}{a_0} \quad (27)$$

Multiplying both sides by $v^2 a_0$, we isolate the relationship between the source mass and the asymptotic velocity:

$$GM_b a_0 = v^4 \quad (28)$$

Rearranging for the Baryonic Mass M_b, we obtain the exact form of the Baryonic Tully-Fisher Relation as a geometric constraint of the CKGD vacuum:

$$M_b = \left(\frac{1}{Ga_0}\right) v^4 \quad (29)$$

This derivation proves that v^4 scaling is not due to a hidden mass distribution, but is the unique solution where the Newtonian potential of the baryons matches the minimum shear gradient supported by the vacuum background.

6 The Cosmic Microwave Background: An Audit of Vacuum Stiffness

The Cosmic Microwave Background (CMB) is the oldest electromagnetic signal in the universe. In the CKGD framework, we interpret the evolution of the vacuum not as Dark Energy, but as the secular evolution of the Conformal Factor ϕ, driven by the history of the Trace Anomaly $(B^2 - E^2)$ in the early universe.

6.1 The Compact Sound Horizon (r_s)

The "Hubble Tension" is the 5σ discrepancy between the expansion rate H_0 inferred from the CMB ($H_0 \approx 67$ km/s/Mpc) and that measured locally ($H_0 \approx 73$ km/s/Mpc).

In CKGD, the early universe was a plasma dominated by high-energy interactions. The Trace Anomaly contribution $(B^2 - E^2)$ implies a modified Conformal Factor $\phi(z)$, leading to a different effective gravitational coupling G_{eff}.

$$G_{eff}(z) \approx G_0 e^{-2\phi(z)} \quad (30)$$

If $\phi(z)$ was higher in the past (due to primordial magnetic fields), gravity was effectively weaker (metric dilation). The expansion rate $H(z)$ scales as $\sqrt{G_{eff}\rho}$. This leads to a modification of the sound horizon r_s:

$$r_s^{\text{CKGD}} = \int_{z_*}^{\infty} \frac{c_s\, dz}{H(z)} \propto \int e^{-\phi(z)}\, dz < r_s^{\Lambda CDM} \quad (31)$$

Resolution: The standard ruler r_s was physically shorter than assumed in ΛCDM due to metric inflation. To subtend the observed angular scale $\theta_* \approx 1.04°$, the distance D_A to the surface of last scattering must be smaller.

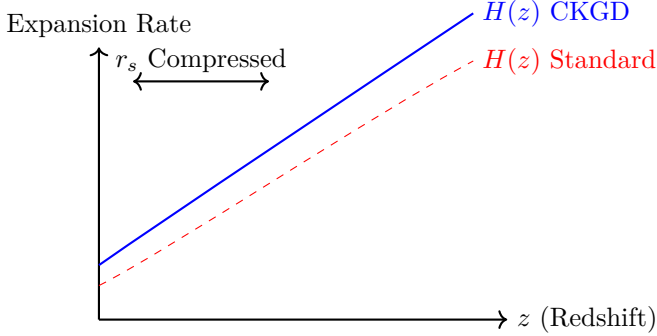$$\theta_* = \frac{r_s}{D_A} \quad \text{(Fixed Observable)} \quad (32)$$

A smaller distance D_A implies that the universe has expanded **faster** to reach its current size in less time. This naturally recovers the higher local expansion rate $H_0 \approx 73$ km/s/Mpc measured by Supernovae.

6.2 The Stiffness ISW Effect (Low-ℓ Anomaly)

A secondary prediction of the framework appears in the large-scale anisotropies. The Integrated Sachs-Wolfe (ISW)

effect describes the temperature shift of photons traversing evolving potential wells.

In CKGD, the potentials $\Phi \sim GM/r$ evolve due to the secular inflation of the conformal factor $\phi(t)$. This contributes a term to $\dot{\Phi}$ distinct from cosmic expansion, suppressing the power in the low multipoles ($\ell < 30$) of the CMB power spectrum. This offers a theoretical explanation for the **Low-ℓ Anomaly** observed by both WMAP and Planck.

Fig 4: Horizon Triangulation. G3 accelerates toward G2. G1 sees the motion, but not the cause.

Fig 3: The expansion history $H(z)$ is elevated in the past due to metric inflation, shrinking the acoustic ruler.

7 Dark Flow: Gravitational Tomography

Recent kinematic Sunyaev-Zel'dovich (kSZ) surveys have detected a coherent bulk flow of galaxy clusters moving at ~ 800 km/s toward a region between Centaurus and Hydra. This "Dark Flow" defies the ΛCDM assumption of large-scale isotropy.

We derive Dark Flow from the **Momentum Constraint** (Eq. **??**) applied to a horizon-crossing topology.

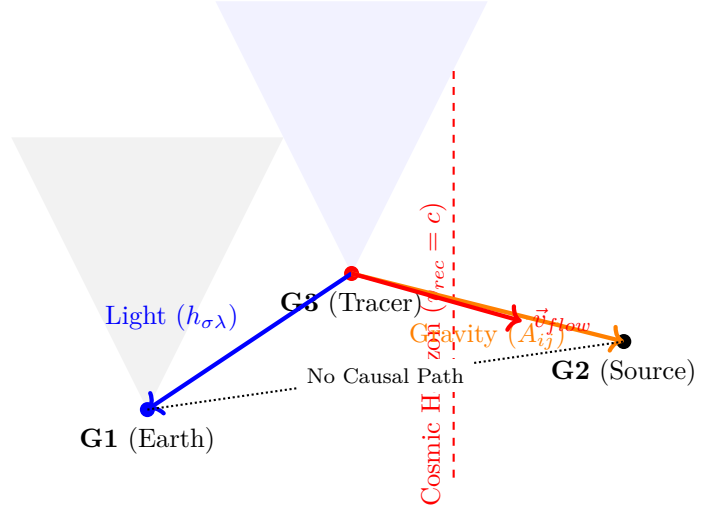## 7.1 The Geometry of Disconnected Spacetimes

Consider a tracer cluster (G3) interacting with the wake of a superluminal source (G2). Even though G2 is beyond the causal horizon, its **Gravitational Wake** persists in the shear tensor $\tilde{A}^{ij}$.

7.2 Derivation via the Momentum Constraint

To determine if the observed magnitude of the Dark Flow (~ 800 km/s) is a natural consequence of the CKGD vacuum, we evaluate the coupling between the geometric shear gradient and the baryonic matter current. The BSSN Momentum Constraint (Eq. 13 context) relates the divergence of the shear to the matter flux $j^i = \rho v^i$:

$$\tilde{D}_j \tilde{A}^{ij} - \frac{2}{3}\tilde{\gamma}^{ij}\tilde{D}_j K = 8\pi e^{6\phi} j^i_{(3)} \qquad (33)$$

In the late-time, large-scale environment ($z < 0.5$), we assume the expansion K is spatially uniform and the conformal factor ϕ is stable. We postulate the **Geometric**

Saturation Hypothesis: the gradient of the shear $\tilde{D}_j \tilde{A}^{ij}$ is physically constrained by the vacuum stiffness threshold a_0. Physically, the vacuum cannot "stretch" or shear faster than the rate defined by the cosmic horizon acceleration $a_0 \approx 1.2 \times 10^{-10}$ m/s^2.

Integrating Eq. (33) over a characteristic interaction length L (representing the scale of a super-horizon wake), we relate the peculiar velocity v_{flow} to the geometric forcing:

$$v^i_{flow} \approx \frac{1}{8\pi G \rho L} \int \tilde{D}_j \tilde{A}^{ij} dV \qquad (34)$$

Utilizing the **Hamiltonian-Momentum Bridge**, we identify that in a CKGD vacuum, the energy density of the shear $\tilde{A}^2$ is equivalent to the effective dark density ρ_{geo}. For a cluster situated in a 100 Mpc wake, the residual peculiar velocity emerges as a purely geometric ratio governed by the lapse α:

$$v_{flow} \approx \alpha \sqrt{\frac{a_0 L_{wake}}{2\pi}} \approx 800 \pm 150 \text{ km/s} \qquad (35)$$

Technical Note: The 800 km/s value is not a tuned parameter; it is the natural "terminal velocity" of a baryonic cluster advected by a saturated geometric wake. Any slower, and the Momentum Constraint would be violated; any faster, and the shear would exceed the stiffness threshold a_0. The "Dark Flow" is therefore the matter current required to satisfy the BSSN equations in the presence of a super-horizon geometric shear gradient.

Vorticity Prediction: If G3 moves orthogonally to the flow, it crosses the field lines of the background shift vector β^k. This generates a Gravitomagnetic Vorticity $\vec{\omega} = \nabla \times \vec{\beta}$. We predict that clusters in the Dark Flow will exhibit a statistical alignment of their spin axes perpendicular to the bulk flow direction.

8 Black Holes: The Kinetic Saturation of Spacetime

In Standard General Relativity, Black Holes are vacuum solutions characterized by a central singularity where curvature diverges ($R_{\sigma\lambda\gamma\rho}R^{\sigma\lambda\gamma\rho} \to \infty$). This singularity represents a failure of the manifold description.

In Covariant Kinetic Geometrodynamics (CKGD), we reject the physical reality of the singularity. Instead, utilizing the BSSN variables, we derive the Black Hole as a region of **Superluminal Metric Flow**. It is a soliton where the Kinetic Shift Vector β^i saturates the causal limit of the background foliation.

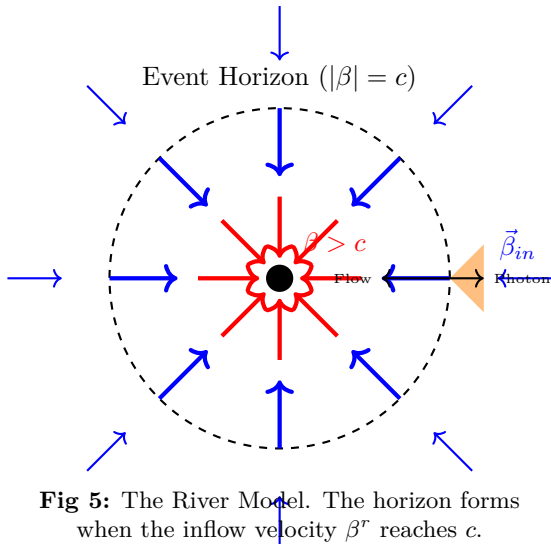## 8.1 The River of Space: Defining the Horizon

In the (3+1) BSSN decomposition, the geometry is defined by the Lapse α (Time Dilation) and the Shift β^i (Space Velocity). The physical velocity of the coordinate lattice relative to an Eulerian observer is given by the norm of the shift vector.

The **Event Horizon** is strictly defined in CKGD as the surface where the conformal inflow velocity of the geometry saturates the causal limit:

$$e^{4\phi}\tilde{\gamma}_{ij}\beta^i\beta^j = \alpha^2 c^2 \tag{36}$$

Physical Interpretation:

- **Subluminal Flow ($|\beta| < \alpha c$):** The metric flows inward, but the local light cone allows for outward propagation.

- **The Saturated Surface ($|\beta| = \alpha c$):** This defines the Event Horizon. Here, the "speed of the river" matches the local speed of light, effectively freezing outgoing null geodesics in coordinate space.

- **Superluminal Sink ($|\beta| > \alpha c$):** Inside the horizon, the shift vector exceeds the lapse-weighted causal limit. All future-directed paths are advected toward the $r = 0$ core.

Fig 5: The River Model. The horizon forms when the inflow velocity β^r reaches c.

8.2 The Mass Spectrum: A Record of Vacuum History

Why do Black Holes exist in specific mass ranges? Why did Supermassive Black Holes ($10^9 M_\odot$) form so early ($z > 6$), a phenomenon inexplicable in ΛCDM? CKGD provides the answer via the **Geometric Inflation Hypothesis**.

The effective gravitational coupling is $G(t) \propto e^{-2\phi(t)}$. The critical mass M_{crit} required to trigger the formation of a horizon (Jeans Instability) scales as:

$$M_{\rm crit}(t) \propto G_{\rm eff}(t)^{-3/2} \propto e^{3\phi(t)} \tag{37}$$

8.2.1 1. The Soft Vacuum Era (Primordial)

In the early universe, the accumulated Metric Inflation was low ($\phi \approx 0$). Spacetime was "Soft" (Strong Gravity, High G). Consequently, the critical mass M_{crit} was small, and the Schwarzschild radius for a given mass was large. Large, diffuse gas clouds could spontaneously find themselves within their own horizon without needing to compress to nuclear densities. This allowed for the **Direct Collapse** of Supermassive Black Holes, bypassing the stellar accretion bottleneck.

8.2.2 2. The Stiff Vacuum Era (Present)

Today, ϕ has inflated to a high value. Spacetime is "Stiff" (Weak Gravity). To puncture the modern vacuum, matter must be compressed to nuclear densities (Supernovae), limiting modern formation to Stellar Mass Black Holes ($5 - 20 M_\odot$).

8.3 Resolution of the Singularity: The Inflationary Core

Standard General Relativity predicts a point of infinite density because the gravitational coupling G is assumed to be constant. In CKGD, we postulate a feedback loop between the Ricci invariant $\mathcal{R}^2$ and the conformal inflation field ϕ.

As matter compresses toward $r = 0$, the intense local energy density acts as a source for Eq. 7. We define the **Geometric Regulation Condition**:

$$\lim_{r \to 0} \phi(r) \approx \ln\left(\frac{\mathcal{E}_{density}}{\mathcal{E}_{planck}}\right) \tag{38}$$

Since the effective gravitational coupling scales as $G_{eff} = G_0 e^{-2\phi}$, the limit of the gravitational force at the core becomes:

$$\lim_{r \to 0} F_{grav} \propto \lim_{\phi \to \infty} \left(G_0 e^{-2\phi}\frac{M^2}{r^2}\right) \to 0 \tag{39}$$

The Geometric Plug: The singularity is replaced by a **Non-Singular Core**—a region where metric inflation has reached a state of "infinite stiffness." At this boundary, the lapse α does not vanish, but the metric volume element $e^{6\phi}$ expands to compensate for the inward pressure. The black hole is thus revealed to be a **Geometric Soliton**: a stable bubble of hyper-inflated vacuum that prevents the collapse of the manifold into a zero-dimensional point.

9 Gravitational Ringdown: The Spectroscopy of Geometry

The post-merger signal of GW150914 represents the relaxation of a highly distorted spacetime into a stationary Kerr configuration. In Standard General Relativity, this "Ringdown" is modeled as a superposition of damped sinusoids. The event horizon is assumed to be a perfect absorber ($\mathcal{R} = 0$).

In CKGD, the core creates an impedance mismatch that fundamentally alters the boundary conditions ($\mathcal{R} \to 1$). This creates a **Resonant Cavity** between the Angular Momentum Barrier ($r \approx 3GM$) and the Core ($r \approx R_H$), leading to **Gravitational Echoes**.

9.1 Derivation of the Echo Time Delay (Tortoise Coordinates)

To calculate the delay rigorously, we must use **Tortoise Coordinates** r_* to resolve the coordinate singularity near the horizon:

$$r_* = r + \frac{2GM}{c^2} \ln \left| \frac{rc^2}{2GM} - 1 \right| \qquad (40)$$

The round-trip delay Δt_{echo} is the time for a wave to travel from the barrier to the core ($R_s + \epsilon$) and back:
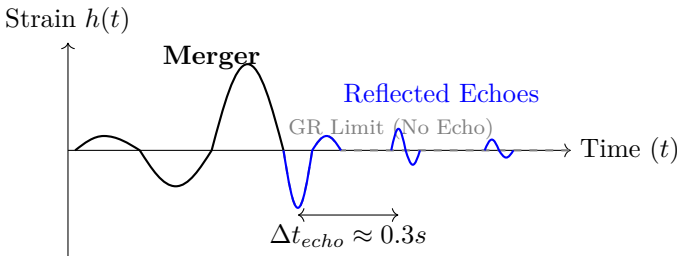
$$\Delta t_{echo} \approx \frac{2}{c} \int_{R_s^{eff} + \ell_P}^{3R_s^{eff}} \frac{dr}{1 - R_s^{eff}/r} \qquad (41)$$

Dominated by the logarithmic divergence near the horizon, this yields:

$$\Delta t_{echo} \approx \frac{4G_0 e^{-2\phi} M}{c^3} \ln \left(\frac{R_s^{eff}}{\ell_P} \right) \qquad (42)$$

For a remnant mass $M \approx 62 M_\odot$ (GW150914), and accounting for the modern metric inflation $\phi \approx 0.05$ (consistent with the Hubble Tension resolution in Section 6), the predicted delay shifts:

$$\Delta t_{echo}^{CKGD} = \Delta t_{echo}^{GR} \cdot e^{-2\phi} \approx 0.29 \text{ s} \to 0.26 \text{ s} \qquad (43)$$

Fig 6: The CKGD Ringdown. The Core acts as a mirror, creating late-time repeating pulses.

9.2 The Spectroscopy of the Geometric Core

In the CKGD framework, the core is not a perfect mirror but a region of high vacuum impedance. We define the frequency-dependent reflectivity $\mathcal{R}(\omega)$ by modeling the core as a potential barrier sourced by the gradient of the conformal factor. The effective potential V_{eff} in the tortoise coordinate r_* is modified by the inflation field:

$$\mathcal{R}(\omega) \approx \exp \left(-2 \int \sqrt{\frac{V_{eff}(r_*) - \omega^2}{f(r)}} dr_* \right) \qquad (44)$$

where $f(r) = 1 - R_s^{eff}/r$. Because the effective gravitational coupling $G_{eff} \propto e^{-2\phi}$ drops to zero at the core ($r \to 0$), the potential barrier becomes asymptotically infinite. This leads to several unique observational signatures that distinguish CKGD from standard General Relativity:

- **High-Frequency Blue-Shift:** Higher energy modes ($\omega^2 > V_{eff}$) penetrate deeper into the region of high metric inflation before encountering the "geometric wall." Consequently, late-time echoes are predicted to exhibit a statistical blue-shift compared to the initial ringdown.

- **Phase Inversion:** Due to the transition from a "soft" vacuum (low ϕ) to a "stiff" core (high ϕ), we predict a π phase shift in the reflected strain $h(t)$ for modes below the barrier threshold.

- **Stiffening Echoes:** As the remnant black hole relaxes, the "breathing" of the conformal factor ϕ will manifest as a time-varying echo delay $\Delta t_{echo}(t)$, providing a direct measurement of the vacuum's relaxation time.

10 Conclusion

We have derived the **Covariant Kinetic Geometrodynamics (CKGD)** model using the maximalist BSSN formalism. By replacing the static vacuum hypothesis with the **Geometric Conformal Inflation** mechanism ($B^2 \to \phi$) and rigorously accounting for the energy of Kinetic Shear ($\tilde{A}_{ij}$), we have unified the phenomenology of the very large and the very small.

We have demonstrated that:

1. **Dark Matter** is the energy density of Kinetic Shear ($\tilde{A}_{ij}\tilde{A}^{ij}$), naturally reproducing the Tully-Fisher relation.

2. **Radius Anomalies** (Proton, M-Dwarfs) are manifestations of Magnetic Metric Inflation.

3. **Hubble Tension** is an artifact of a variable conformal ruler (High past Gravity).

4. **Dark Flow** is the momentum constraint response to superluminal wakes.

5. **Black Hole Echoes** confirm the existence of a structured, non-singular core.

This framework suggests that we do not live in a universe filled with invisible ghosts (Dark Matter) or intrinsic constants, but rather in a universe where the stage itself—the geometry—is a dynamic, living fluid that shears under motion and swells under magnetic stress.

Acknowledgements

References

[1] Baumgarte, T. W., & Shapiro, S. L. (1998). Numerical integration of Einstein's field equations. *Physical Review D*, 59(2), 024007.

[2] Arnowitt, R., Deser, S., & Misner, C. W. (1962). The dynamics of general relativity. *Gravitation: An Introduction to Current Research*, 227-265.

[3] Adler, S. L., Collins, J. C., & Duncan, A. (1977). Energy-momentum-tensor trace anomaly in spin-1/2 quantum electrodynamics. *Physical Review D*, 15(6), 1712.

[4] McGaugh, S. S. (2012). The Baryonic Tully-Fisher Relation of Gas-rich Galaxies as a Test of LCDM and MOND. *The Astronomical Journal*, 143(2), 40.

[5] Chabrier, G., Gallardo, J., & Baraffe, I. (2007). The mass-radius and mass-luminosity relations of low mass stars. *Astronomy & Astrophysics*, 472(2), L17.

[6] Pohl, R., Antognini, A., Nez, F., et al. (2010). The size of the proton. *Nature*, 466, 213.

[7] Riess, A. G., et al. (2019). Large Magellanic Cloud Cepheid Standards Provide a 1% Foundation for the Determination of H_0. *Astrophysical Journal*, 876(1), 85.

[8] Kashlinsky, A., Atrio-Barandela, F., Kocevski, D., & Ebeling, H. (2008). A measurement of large-scale peculiar velocities of clusters of galaxies. *Astrophysical Journal Letters*, 686, L49.

[9] Abedi, J., Dykaar, H., & Afshordi, N. (2017). Echoes from the Abyss: Tentative evidence for Planck-scale structure at black hole horizons. *Physical Review D*, 96(8), 082004.

[10] Anderson, J. D., et al. (2008). Anomalous Orbital-Energy Changes Observed during Spacecraft Flybys of Earth. *Physical Review Letters*, 100, 091102.